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# Vegetative Delineation of Coastal Salt Marsh Boundaries

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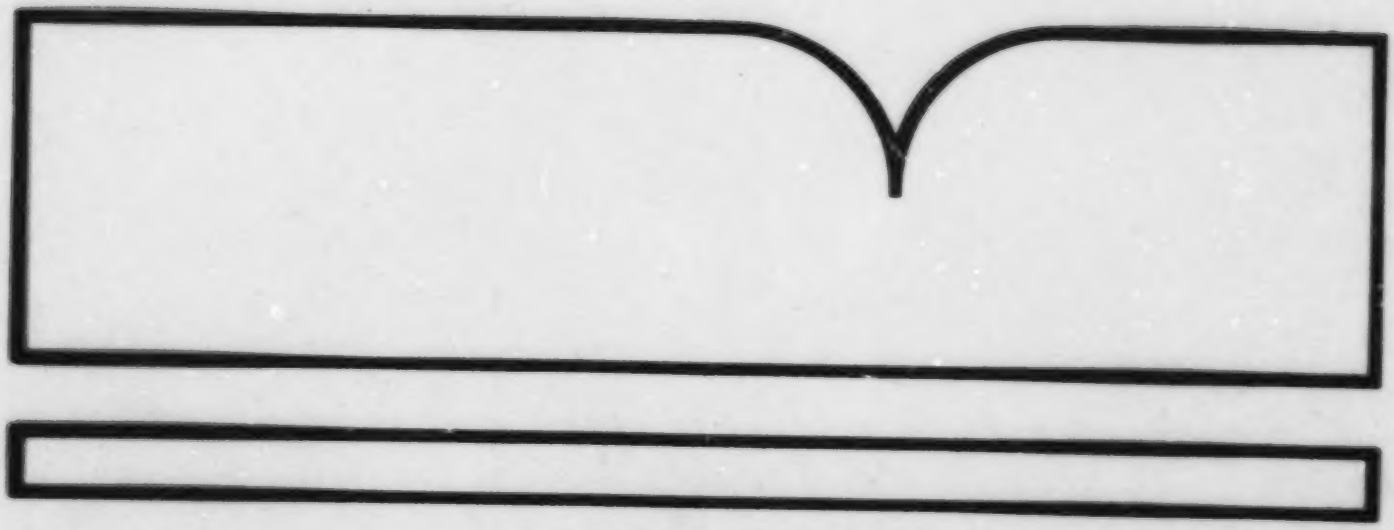

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# VEGETATIVE DELINEATION OF COASTAL SALT MARSH BOUNDARIES

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Concurrent with increased awareness of salt marsh values and potentials, however, has been the rapid conversion of coastal marsh to urban, industrial, and agricultural uses through diking, filling, and construction activities (Darnell 1976). Recent federal legislation is designed to retard these alterations and thereby protect the nation's remaining wetland resources. Most notable are the Federal Water Pollution Control Act Amendments of 1972 and 1977 (Water Act) which, in Section 404, establish a permit review process to regulate dredge and fill projects.

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## ABSTRACT

Legislation mandating the protection of wetlands and current pressures to convert them to other uses emphasize the need to accurately determine a wetland-upland boundary. We investigated six methods designed to establish such a boundary based on vegetation. Each method was applied to a common data set obtained from 295 quadrats along 22 transects between marsh and upland in 13 Oregon and Washington intertidal saline wetlands. The multiple occurrence, joint occurrence, and five percent methods required plant species to be classified as salt marsh, upland, and non-indicator; cluster and similarity methods required no initial classification. Close agreement between wetland-upland boundaries determined by the six methods suggests that preclassification of plants and collection of plant cover data may not be necessary to determine a defensible boundary.

# INTRODUCTION

Two decades of intensive research following the suggestions of Odum (1961) and the work of Teal (1962) have firmly established positive values for undisturbed coastal salt marshes. These intertidal wetlands are noted for high macrophyte production and for export of energy-rich organic detritus and dissolved organic carbon to estuarine waters. They serve as juvenile fish and wildlife habitat, buffer to erosion of sediment, and potential water purifiers.

Concurrent with increased awareness of salt marsh values and potentials, however, has been the rapid conversion of coastal marsh to urban, industrial, and agricultural uses through diking, filling, and construction activities (Darnell 1976). Recent federal legislation is designed to retard these alterations and thereby protect the nation's remaining wetland resources. Most notable are the Federal Water Pollution Control Act Amendments of 1972 and 1977 (Water Act) which, in Section 404 establish a permit review process to regulate dredge and fill projects.

To implement Section 404 requires that those involved in the review process be able to: (1) identify wetland; and (2) determine wetland boundaries. Yet, while wetland may be identified by noting the presence of standing water and plants adapted to saturated soil conditions, the determination of the upper limit is difficult. Instead of exhibiting a sharp break, the characteristics of wetland are more likely to gradually shift to those of upland, defined here as terrestrial non-wetland, along a transition. In salt marsh, the influence of the tide diminishes with increasing surface elevation, soils become better drained, and vegetation gradually changes. An ecotone with interdigitation of marsh and upland plant species occurs between the two systems (Fig. 1).

To better understand the nature of the marsh-upland ecotone and to develop methods of delineating a legally defensible intertidal salt marsh boundary, the U.S. Environmental Protection Agency in conjunction with the U.S. Army Corps of Engineers began a major research effort in 1975. After three pilot projects were completed (NOS 1975, Frenkel and Eilers 1976, Jefferson 1976), five groups were funded to investigate transition zones and upper limits. They covered salt marshes along the coasts of California (Harvey et al. 1978); Oregon and Washington (Frenkel et al. 1978); Alaska (Batten et al. 1978); Delaware, Maryland, Virginia, and North Carolina (Boon et al. 1978); and freshwater marshes along the shores of Lake Superior, Lake Michigan, and Lake Huron (Jefferson 1978). The reports provide a floristic description of marsh-upland ecotones and identify approaches to boundary determination based on vegetation.

The purpose of this paper is to: (1) evaluate the methods used by these researchers; (2) present alternative methods; and (3) recommend the best approach to wetland boundary delineation based on vegetation. The methods presented are applicable to wetland-upland boundary determination in general, not to salt marshes alone. However, we do acknowledge that vegetation should not be the only criteria considered. The best approach will incorporate an analysis of vegetation, soil, and hydrology. The methods considered here are a first approximation, but as our knowledge of physical factors across the wetland-uplan ecotone increases methods for defining boundaries will be refined. At the moment we must rely primarily on a vegetation approach.

## METHODS FOR BOUNDARY DETERMINATION

The methods of determining wetland boundaries presented by the researchers listed above range from those emphasizing indicator species with little

quantitative data, to those requiring classification of all plant species recorded and intensive quantitative treatment. First, we consider the less quantitative approach favored by Batten et al. (1978) and Jefferson (1978); then the more quantitative methods of other researchers. To this we add other quantitative approaches.

## Indicator Species

Batten et al. (1978) investigated Alaskan coastal salt marshes and collected information on plant species percent cover from quadrats located along the elevation gradient between marsh and upland. Based on their data and knowledge of plant species habitat preference, they developed lists of indicator species that signal the shift from salt marsh to terrestrial upland or freshwater marsh. The lower limit of the transition zone (LTZ) was established at the point where species "abundant" in upland or freshwater wetland first become "abundant" in the marsh. The upper limit of marsh (ULM) was set at the point where all the species characteristic of the vegetation type bordering the marsh were present in "appropriate amounts". No definition of "abundant" or "appropriate amounts" is given and thus establishing an actual boundary in the field using this approach would be subjective and ill-suited to situations involving legal scrutiny.

Jefferson (1978) likewise developed indicator plant species lists from the study of freshwater marshes along the shores of the Great Lakes. Her treatment of the marsh-upland ecotone is comprehensive, yet little attention is given to boundary delineation. She states that "by using the community descriptions and lists of dominant, prevalent, and differential species, detection of the ecotone and its limits should be facilitated." As with

Batten et al. (1978), this approach requires much subjective judgment and may be expected to yield only an approximate boundary determination.

Five Percent

The intial approach of Boon et al. (1978) and Harvey et al. (1978) was similar to those above but included boundary delineation. Following acquisition of plant cover estimates from transects along the transition from marsh to upland, a "five percent" method was used to define the upper limit of the transition zone as the point "at which the amount of ground coverage by upland plants is at least five percent and is contiguous with the upland proper" (Boon et al. 1978). The lower transition limit is defined similarly--upland plant coverage less than five percent. Both research groups classified plant species as to marsh, transition, upland (Boon et al. 1978); or marsh, upland, non-indicator (Harvey et al. 1978) and presented results graphically. Harvey and associates applied the following procedures: (1) when a five percent cover of the appropriate type (either marsh or upland) occurred in a quadrat with no trace in the adjacent, more distal quadrat, the quadrat with five percent cover was marked as the transition; (2) if the adjacent quadrat distal to the five percent cover plot had a trace of the vegetation type in question, the adjacent quadrat was marked as the transition limit; (3) if two plots in sequence had a trace of either vegetation type, the more distal quadrat was marked as the limit; (4) if the five percent cover level fell between two quadrats, the limit was located by interpolation; (5) if no overlap of upland and marsh species occurred either due to bare ground and/or cover by non-indicator species, a point midway between quadrats in which each type was represented was chosen (Fig. 2a).

Joint Occurrence

After applying the five percent method, Harvey et al.(1978) sought a "quicker, easier, but equally accurate approach." Their choice was a modification of Fager's (1957) measure of joint occurrence which takes the form

$$I_{MU} = \frac{2J}{nM + nU}$$

where, for any single quadrat, J is the number of joint occurrences of marsh and upland species, nM is the number of marsh species, and nU is the number of upland species. Non-indicator species are disregarded.

Plotting $I_{MU}$ for quadrats along a transect shows a series of zeros for pure wetland, because there are no joint occurences, followed by a rise to a peak in the transition and a fall to zero again in pure upland. In practice, however, Harvey et al. (1978) found it difficult to interpret such a graph when natural or man-made "patchiness" was present. This problem was largely eliminated by computing a standardized index (SI) then a standardized cumulative index (SCI) for each quadrat:

$$SI_i = \frac{I_{MU_i}}{\sum_{i=1}^{n} I_{MU_i}} \text{ and } SCI_i = \sum_{i=1}^{Q} SI_i,$$

where n is the total number of quadrats and Q is the quadrat for which SCI is computed. After plotting SCI values, Harvey et al. (1978) identified the lower and upper limits of the transition as 0.5 m above the rise of the data line from the abscissa and 0.5 m above SCI = 1.0, respectively (given 1 m distance between sample quadrats or one-half the distance if greater than 1 m)

(Fig. 2b) Close agreement between the SCI and the five percent method transition boundaries was observed.

Multiple Occurrence

Frenkel et al. (1978) analyzed species distribution patterns to develop four categories of species--low marsh, high marsh, non-indicator, and upland--and computed a score for quadrat data collected along transects between marsh and upland. The "multiple occurrence method" (MOM) score (M) required the assignment of a weighting coefficient:

| Species Type | Weighting Coefficient |
|---|---|
| Low marsh | 2 |
| High marsh | 1 |
| Upland | -2 |
| Non-Indicator | 0 |

The quadrat score was calculated as

$$M = \sum_{i=1}^{n} W_i C_i,$$

where $W_i$ is the weighting coefficient for species $i$, $C_i$ is cover value for species $i$, and $n$ is total number of species in the quadrat sample. Cover values were after Daubenmire (1959): 0-5% = 1, 5-25% = 2, 25-50% = 3, 50-75% = 4, 75-95% = 5, 95-100% = 6. Species present but with negligible cover were disregarded.

Positive M values were interpreted as marsh, the upper limit of marsh was defined as $M = 0$, and $M < 0$ denoted upland. However, further interpretation was necessary because M values did not always descend to a single $M = 0$ and thereafter remain negative. Two additional cases were noted. One

contained more than one M = 0 in succession, and the other with M scores alternating above and below zero. In both cases, the portion of the transect between first and last M = 0 were considered as the transition zone and the upper limit of marsh was placed midway through this zone. In our interpretation of this method we have assigned the upper limit of the transition zone as the ULM (Fig. 2c).

Cluster

If marsh and upland are floristically different, cluster analysis (Boesch 1977) of quadrat data collected along tansects between the two systems might be used to identify wetland limits. Such an approach would have the advantage of not requiring preclassification of plant species into "marsh," "upland," "non-indicator." We chose the Bray-Curtis dissimilarity measure (Clifford and Stephenson 1975),

$$Djk = \frac{\sum_{i=1}^{n} x_{ij} - x_{ik}}{\sum_{i=1}^{n} (x_{ij} + x_{ik})},$$

where $x$ is cover value for species $i$ in quadrats $j$ and $k$, and $n$ is the total number of species. A "flexible" fusion strategy with Beta = -0.25 (Boesch 1977) was utilized. The end product is a dendrogram showing quadrat clusters which form at decreasing levels of dissimilarity (Fig. 2d). The upland cluster was identified as that containing the highest numbered quadrats (when quadrats were numbered from wetland to upland). The upper limit of marsh was interpreted as being half the distance on the transect between the lowest numbered member of the upland cluster and the highest numbered member of the next

lowest group of quadrats. This second group was identified as "transition" if three clusters were present.

Similarity ISJ and ISE

By computing the level of similarity in species content of adjacent quadrat samples along a transect and graphing these values, we expected to observe a decrease in similarity at the marsh-upland border. In this case, two measures were chosen. One was Jaccard's index (Mueller-Dombois and Ellenberg 1974) which requires binary data (presence-absence):

$$ISJ = \frac{c}{a + b + c} \times 100,$$

where c is the number of species common to both quadrats, a is the number of species unique to the first quadrat, and b is the number of species unique to the second quadrat. The other was Ellenberg's (1956 in Mueller-Dombois and Ellenberg 1974) modification of Jaccard's index which accepts species quantities:

$$ISE = \frac{Mc:2}{Ma + Mb + Mc:2} \times 100.$$

Here, Mc is the sum of cover values of species common to both quadrats, Ma is the sum of the cover values of the species restricted to the first quadrat, and Mb is the corresponding sum for species restricted to a second quadrat. Species noted as present but with negligible cover were assigned a value of 0.25 (Fig. 2e and f).

## COMPARISON OF METHODS

To compare the results obtained by the quantitative methods presented above (excluding the indicator species method), each method was applied to a common data set. Twenty-two transects (12%) were chosen at random from the 190 sampled by Frenkel et al. (1978). The data were collected from 50 x 50 cm quadrats. Transects were located with one end well into wetland, the other well into upland, and the orientation parallel to the elevation gradient. Plant species in each quadrat were recorded as to cover class (Daubenmire 1959) except that those with negligible cover were assigned "present" status only. Categorization of plant species as to marsh, upland, etc., was not modified. As LTZ and ULM were calculated by each method, careful note was made of the time involved and ease of application. Effort was concentrated on comparison of ULM identification because of its direct relationship to jurisdictional questions. The ULM was considered to be synonymous with the upper limit of the transition zone.

Data presented in Table 1 reveal close agreement in LTZ and LUM positions obtained by the six methods. ULM for 2 transects (0808 and 1606) was not identified by all methods, suggesting that the transects did not extend far enough to include both marsh and upland quadrats. ULM location agreed within 1.0 m on 9 of the remaining 20 transects (45%) and within 2.5 m on 13 transects (65%). The range of ULM estimates was greatest for transect 1703 (25.5 m), but cluster and similarity plots for this transect showed discontinuities at positions in agreement with other methods that could be interpreted as ULM. In general, methods with species classification built in (five percent, joint occurrence, and multiple occurrence) exhibited low intra-group variability, as did those without species classification.

All methods, with the exception of cluster, involved simple calculations that can be done by hand. Cluster required a computer. Little time difference was involved in applying each method given basic field data and plant classifications, so that the choice of method should be attuned to time available for field work and the availability of a list of indicator species.

Perhaps the most important result of this comparative treatment was that use of species presence-absence yields ULM positions identical or nearly identical to those requiring species percent cover. Thus, the extended field effort required to obtain plant cover is not necessary and the greatest return for time spent might be expected from utilizing species occurrence only.

## DISCUSSION AND RECOMMENDATIONS

The above methods fall into two basic groups. The first comprises five percent, joint occurrence, and multiple occurrence and is characterized by reliance on pre-established lists of wetland and upland indicator species. Botanical expertise is required but, theoretically, a valid ULM determination could be made without in-depth knowledge of wetland ecology.

The second group--cluster, similarity ISJ and similarity ISE--does not require preclassification of plant species. Instead, it is assumed that species are distributed along transects in such a way as to form groups characteristic of wetland, transition, and upland, and that these groups can be identified objectively. This study suggests that this approach is viable and that results are comparable to those obtained by preclassification methods. Cluster and similarity methods are most sensitive to normal vegetation patterns and require interpretation based on ecological knowledge as transect 1703 illustrates. A ULM of 31.5 m was chosen, but it is likely that a

position closer to 7.0 m as indicated by five percent, joint occurrence, and multiple occurrence would have been the selected ULM, given on-site review. All six methods should be viewed as tools with strong indicator value and whether classification of plant species is involved or not, the final boundary decision should involve sound ecological judgment.

A general vegetative approach to wetland boundary identification is outlined in Figure 3. If classification of plants is available, the joint occurrence method may be best because it reduces field time and yields results close to the five percent and multiple occurrence methods. If accepted plant classifications are unavailable, as is the present case for most freshwater wetlands, the cluster method or similarity ISJ applied to presence-absence data may provide defensible boundaries and have the added advantage of helping to establish a classification. Even if the requisite information needed to apply the joint occurrence method is available, it is still advisable to employ either cluster or similarity ISJ or both to support the initial decision.

Although a vegetative approach to ULM determination is likely to be satisfactory in that plant distributions reflect environmental conditions, our present knowledge of physical factors, such as soils and hydrological regimes, across the transition is very limited. It is assumed that certain plants indicate physical conditions of wetland, transition, and upland, but we do not know tolerance limits for species so classified. Research underway at the U.S. Environmental Protection Agency and U.S. Army Corps of Engineers is designed to provide a more holistic treatment of the wetland boundary problem. Physical factors between wetland and upland are being intensively monitored at numerous wetland sites; greenhouse studies are testing species tolerance to various field conditions, such as inundation and soil saturation, and methods are being devised to incorporate both vegetation and physical factors in

wetland boundary identification. In the near future, the ability to establish boundaries will be enhanced beyond the tenuous reliance on vegetation indicators alone.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

Fig. 1. Photograph showing marsh and ecotone

Fig. 2a-f. Six methods for one transect

Fig. 3. Flow diagram

Table 1. Comparison table